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A Method for Making Three-dimensional Reproductions of Bones and Fossils

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Abstract

The production and dissemination of high quality casts is an integral part of the paleontological and anatomical sciences. However, detailed descriptions of the techniques for making high resolution, three dimensional reproductions are not readily available.

The casting laboratory at the Cleveland Museum of Natural History has developed a technique for making detailed, dimensionally stable reproductions of fossil and skeletal materials. Experimentation with molding compounds has shown Dow Corning Silastic, RTV E, to be an excellent material for our purpose, in spite of its extreme sensitivity to certain organotin compounds. Proper preparation of the original specimens prior to molding is therefore crucial in the molding procedure. The original specimen is placed in a clay base and is covered with a number of thin coats of deaired silastic. A plaster jacket is formed over the flexible rubber layer to prevent angular distortion. The half mold is inverted, the clay removed, a thin coat of parting compound painted over the exposed silastic and the process is repeated. Casts are made in urethane plastic or dental stone. Hollow casts are made by partially filling and rotating the mold. These easily learned techniques allow the production of three dimensional casts of exceptional quality.

Introduction

The casting facilities of the Department of Physical Anthropology at the Cleveland Museum of Natural History were developed in 1975. At that time, the primary function of the casting laboratory was to duplicate the three-to-four-million-year-old hominid fossils that Donald Johanson had recently discovered in the Hadar region of Ethiopia. The techniques developed to mold and cast these fossils are now being used to replicate select specimens from the Hamann-Todd Osteological Collection, a large assemblage of recent human and nonhuman primate skeletal materials which is curated by the Museum's Department of Physical Anthropology. We believe that these procedures produce accurate, stable reproductions of unequaled quality in both plaster and plastic. They are, moreover, easily learned and are readily adaptable to many situations, both field and laboratory.

This paper specifically describes the molding and casting techniques developed and presently in use in the Laboratory of Physical Anthropology of the Cleveland Museum of Natural History (Smith and Latimer, 1985; 1986). It is intended for those with some experience in molding and casting and is not meant to be a review of, or introduction to casting techniques. Several articles, however, have detailed some of the many other molding and casting techniques that are currently in use (Burke, 1983; Heaton, 1980; Jensen, 1961; Madsen, 1974; O'Donnell and Hanley, 1983; Parsons, 1973; Quinn, 1940; Reser, 1981; Rigby and Clark, 1965; Schrimper, 1973; Siveter, 1982; Waters and Savage, 1971). Also, because molding and casting is a "hands-on" activity we encourage beginners to practice with less valuable objects.

As many of the materials used in casting procedures are potentially hazardous (*e.g.* organic solvents, epoxies, urethanes), instructions should be followed carefully. Protective clothing including gloves (we recommend latex disposable) should be worn. Adequate ventilation, such as a fume hood, is a necessity during the mixing of the urethane plastics, Dynacast and MasterCast, and the application of trichloroethane, Glyptal, Krylon and silicone sprays. It is also advisable to leave the newly unmolded plastic casts under the hood for a 24-hour curing period.

Our presentation is divided into three sequential sections. The first section describes specimen preparation before molding, the selection of the molding material and the seven basic steps of the molding process. The second section describes casting techniques for the production of plaster and plastic casts. The final section details finishing methods, repair of defects and painting techniques. The rotating casting machine used to make hollow casts is described in Appendix 2.

Molding

Molding is the most time consuming part in the entire procedure and should be done very carefully as mistakes are very difficult to remedy later. The selection of an appropriate molding material is crucial, as is the proper preparation of the original specimen prior to molding. The following description and illustrations will, for demonstrative purposes, focus on a simple two-part mold. However, the same techniques can be applied with slight modification to create a more complex, multiple-piece mold.

Specimen Preparation

The primary objective in mold making is to reproduce the greatest amount of detail without placing the original specimen at risk. In order to maximize mold detail and simultaneously protect the original specimen, preparation techniques must be followed carefully.

A good mold will reproduce microscopic detail. It is therefore very important that the surface of the original specimen be cleaned so that it is free of any rubber from previous moldings, unnecessary adhesives, clay, pieces of matrix, plaster, etc.

At this point, because the physical properties of the molding rubber could be affected by prior specimen preparation, it is necessary to discuss the choice of molding material. Our experience with various molding compounds has shown that Dow Corning Silastic RTV E (Appendix 1) molding rubber is superior in its ability to retain intricate detail over the duration of the mold life. A major drawback, however, is its extreme sensitivity to certain compounds. Contamination by sulfonates, amines and neoprene can severely inhibit this rubber's vulcanization. It is therefore necessary to review the original specimens "history" as to how and when was it originally prepared and what types of materials (especially adhesives) were used. It is especially important to find out if the specimen had been molded previously. This latter issue is pertinent because many molding compounds are incompatible with one another and the residue from a previous molding may result in inhibition of the silastic rubber. In light of this, we strongly encourage that detailed and easily accessible records are kept regarding all preparation, molding and casting procedures.

Finally, some fossil deposits naturally contain elements that will inhibit molding rubber. It has been our experience that fossils taken from a coal or shale matrix are likely to result in some degree of molding rubber inhibition due to the high sulfur content in these materials. In any case the important point is to test all specimens for chemical contamination prior to molding. This axiom holds for modern bone specimens as well as fossils; all originals must be checked for chemical contamination.

Molding rubber inhibition has occurred if the rubber is gummy or uncured after the 24-hour curing period has elapsed. Compatibility should be tested by placing a drop of the mixed, uncured rubber on the surface to be reproduced. An individual drop of the silastic should be placed on each area exhibiting different surface structure or coloration. Again, we strongly recommend testing any object that is suspected as a potential problem; uncured, semi-liquid silastic is very difficult to remove.

In the event of contamination, other silastics, for example Silicone H (see Dow Corning Product Guide for a list of Silastics), which are not as easily inhibited, may be used in place of Silastic E. Although this publication recommends the use of Silastic RTV E, the procedures can be easily modified for use with other Silastic rubbers and molding materials.

Chemically contaminated areas can often be cleaned with a weak organic solvent such as acetone and, if necessary, treated with a barrier coat, such as Glyptal lacquer cement (Appendix 1) dissolved in acetone. After

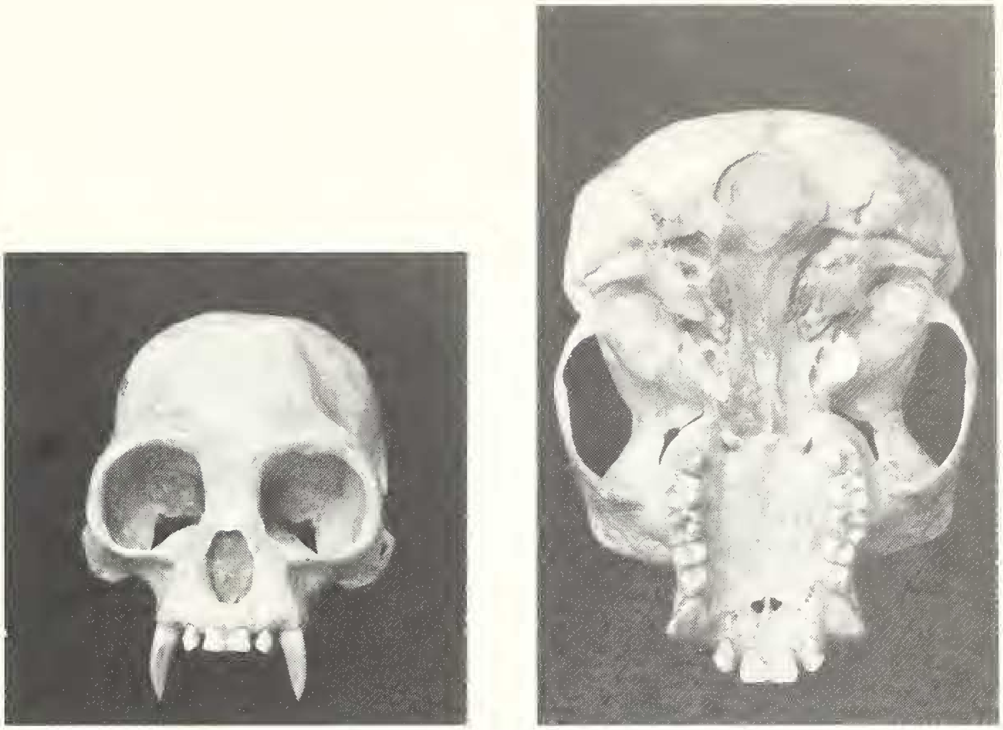

FIGURE 1. *The frontal and inferior view of an adult male gibbon cranium that has been prepared for molding. Note that the nasal aperture and all foramina and canals are blocked with clay.*

coating the specimen or specific areas of the specimen with thinned Glyptal, the surface should be washed with acetone to reduce surface glaze. It is important to wait several hours to allow any remaining solvent to volatilize, a step which can be hastened by placing the specimen under a heat lamp. Because acetone will dissolve most commonly used adhesives, care must also be taken to ensure that any prior reconstructions or repairs are not damaged. Again, it is necessary to check that the adhesives are completely dry as any partially dried glue or softened adhesive will result in contamination of the molding rubber. Water when present on the original specimens can also result in inhibition.

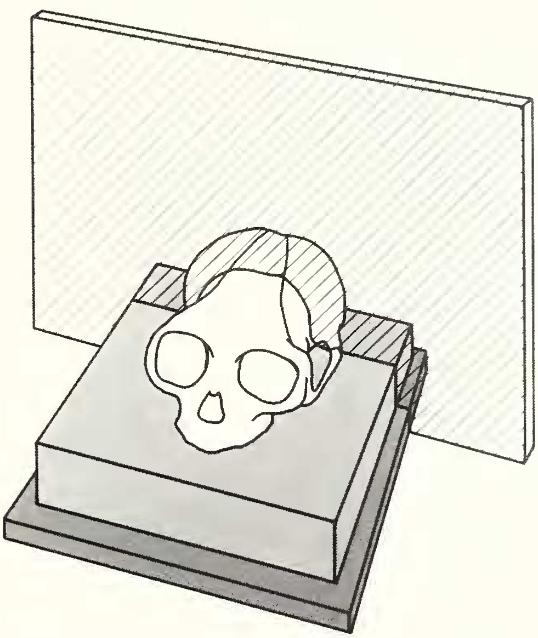

FIGURE 2. *Coronal section through skull showing reference plane used in Figures 5,7,9,11,13,15 and 16.*

Having once tested the specimen to ensure its compatibility with the molding rubber, it is then necessary to "stabilize" fragile areas so they will not be damaged in the subsequent procedures.

The glyptal acetone mixture described above can also be used to stabilize or strengthen fragile surfaces that might otherwise be damaged during the molding process. Painting especially delicate surfaces with petroleum jelly dissolved in 1-1-1 Trichloroethane (CH_3CCl_3) will prevent adhesion of the molding rubber and in so doing will facilitate removal of the original from the mold. This latter step reduces mold detail, but is often necessary with extremely fragile specimens. If the petroleum jelly solution is used, it must be carefully removed from the original specimen after the molding procedure is completed. After checking for molding rubber compatibility and stabilizing any especially fragile areas, the next step is to block small openings to prevent the penetration of the liquid molding rubber. This includes openings such as exposed medullary canals, foramina, areas between teeth or deep cracks in the surface of the specimens. These should be blocked to within a few millimeters of the external surface with clay or beeswax. We use Plastalina clay, a wax-type plastic clay,

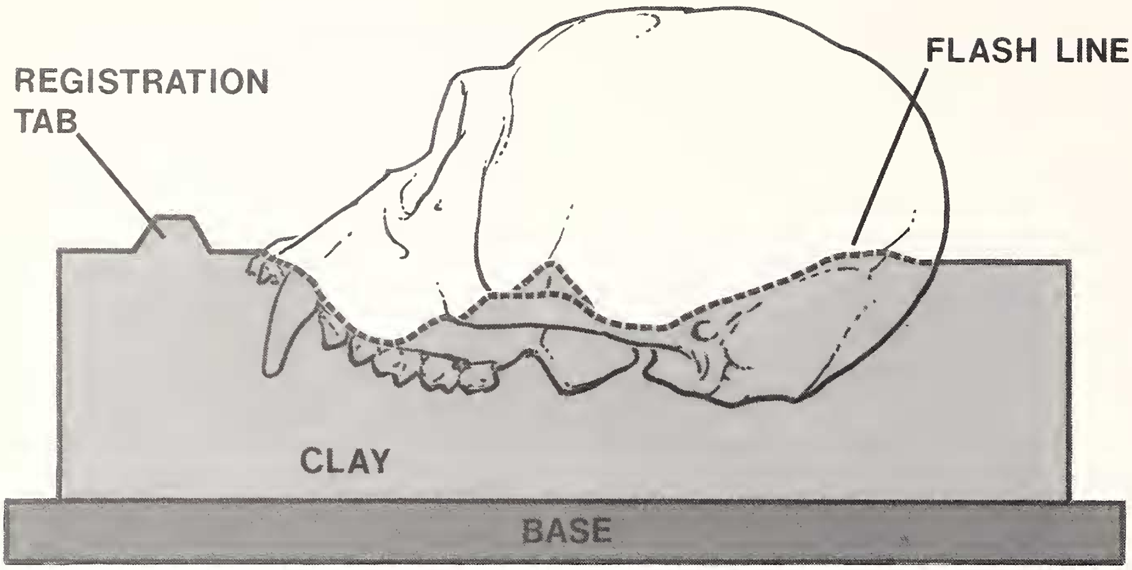

Figure 3. *Step 1 — Lateral view of the skull partially embedded in clay block (shown as transparent) to demonstrate position of flash line. Note that the flash line follows natural contour lines and ridges, such as the edge of the tooth row, the zygomatics and the nuchal ridge along the back of the skull.*

but any clay which is compatible with the silastic rubber can be used. Again, it is important to check that the clay is compatible with the molding rubber. Many kinds of oil-base modeling clay inhibit RTV curing.

We have found when blocking small foramina, beeswax due to its tackiness, works better than clay. In addition, because it is sticky and semi-transparent beeswax can also be used to create a thin "window" of material to block small openings. The resulting membrane of casting material formed in the completed cast can be easily removed with a needle or sharpened dental tool. This technique is especially useful when molding jaws and teeth where spaces between individual teeth must be maintained. Again, if there is any question regarding compatibility, any clays and/or waxes should be tested prior to use.

Figure 4. *Step 1 — Skull partially embedded in clay block to establish part line. Note elevated tabs which act as registration guides. Note also that all elevations and depressions on the face of the mold are angular with planar surfaces.*

Deep cracks or fissures in the original makes "demolding" of the original as well as subsequent casts difficult. If this is judged to be the case, cracks and fissures should be blocked or filled to within a millimeter or two of the surface with wax or clay. Reconstructions of this type can strengthen an especially fragile original, but these must be sharply delimited so that there is no confusion on the finished cast as to the reconstructed and original areas.

We believe that permanent fossil reconstructions should, when possible, be done on highly detailed plaster casts and not on actual specimens. However, if for some reason it is necessary to reconstruct an original specimen, the material chosen must be dimensionally stable as well as reversible and easily removed. Epoxy putty is a material which, when soft, can be configured to a particular shape and then allowed to dry away from the original specimen. Once hardened, the putty can be sanded and shaped and then glued in position with a reversible adhesive. Plaster or clay should not be utilized for fossil reconstructions as these materials are very difficult to remove from the surface of the bone. In addition, clay-like materials shrink as they age which can result in serious damage to the original.

Making the Mold

The molding procedure is discussed and illustrated in seven sequential steps to make it easier to follow the instructions. Please note that much of the important detail is contained in the figure captions. The specimen used in this example was a male gibbon (*Hylobates*) skull (Figure 1). Although the methods discussed here are for a two piece

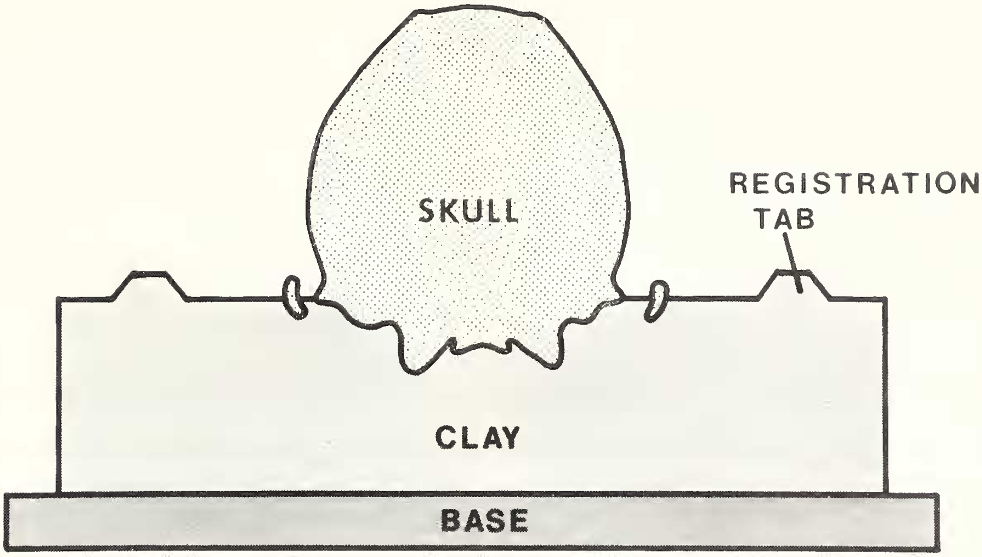

Figure 5. *Step 1 — Coronal section.*

mold, the same basic procedures are followed for a multiple-piece mold. However, because of the extra part-lines and registration problems in complex molds, they should always be made as simple as possible. Specimens which are substantially larger or smaller than the gibbon skull will require some modification of the procedures.

Step 1

The gibbon skull is partially embedded in clay to establish the mold "part" line. The positioning of the "part" or "flash" line around the specimen is critical and important anatomical features must not be obscured. Furthermore, deep undercuts and especially fragile areas must be taken into account when designing the mold to ensure that the original and plaster casts can be removed from the completed mold without damage. In the sample specimen the flash line is positioned to follow the natural contours of the skull and to produce a two-part mold, one-part approximately two-thirds of the total volume of the skull (Figures 3 and 4). This is an important factor when pouring hollow casts, when the volume of casting material used is approximately two-thirds of the total volume of the specimen (see *Casting in Plastic*, this article). Molds that are primarily for plaster casts are more easily handled when the two parts are of equal size (see *Casting in Plaster*, this article) but we have found that problems with registration occur if one part of the mold is less than one-third of the volume of the specimen. Thus the flash-line in the *Hylobates* skull was designed to follow natural lines and ridges on the skull, along the edge of the tooth row and zygomatics and the nuchal ridge.

The clay is formed into a rectangular block which is deep enough to accept approximately half of the specimen. We find that the easiest way to do this is to roll the clay into approximately 1cm-thick slabs. We have tried melting the clay and pouring it into shallow pans to make the clay slabs but this procedure proved less than satisfactory for numerous reasons and we now simply roll the clay mechanically. Rolling can be accomplished with a baker's rolling pin, a process made easier by first working the clay under a heat lamp. In addition, a mechanical wringer such as those used on old fashioned washing machines also works to roll the clay slabs. If possible, it is important to keep the clay block in a square or rectangular shape with vertical walls as this will assist mold registration in later stages. Also, although the block must be of adequate size to accept the original, it should not be much more than 3cm to 5cm larger on any side. This facilitates handling of the completed mold (small molds are easier to manipulate) and also allows the use of a dental irrigation syringe to inject plaster into the closed mold (see below).

After making sure that the clay is deep enough, it is placed on a base made of particle board, plywood or plexiglass. We recommend spraying the base with silicone, or putting wax paper or a paper towel between the clay and the base, to prevent the clay from sticking. The outline of the specimen is then inscribed on the clay surface and a hole is cut large enough for the specimen to be inserted with the predetermined part-line in the same plane as the clay surface. Small amounts of clay are added as needed and pushed against the specimen along the part-line, leaving a clean, sharp contact continuous with the plane of the clay. A small double bladed, stainless steel spatula with the tips of both the rounded and tapered ends bent to a 45∞ angle is an excellent tool for this purpose.

In cases where the natural topography of the specimen requires a depression or elevation of the clay, the edges should be sharply delineated and perpendicular. As much of the clay surface as practical should be smooth and horizontal in order to minimize potential shear strains and

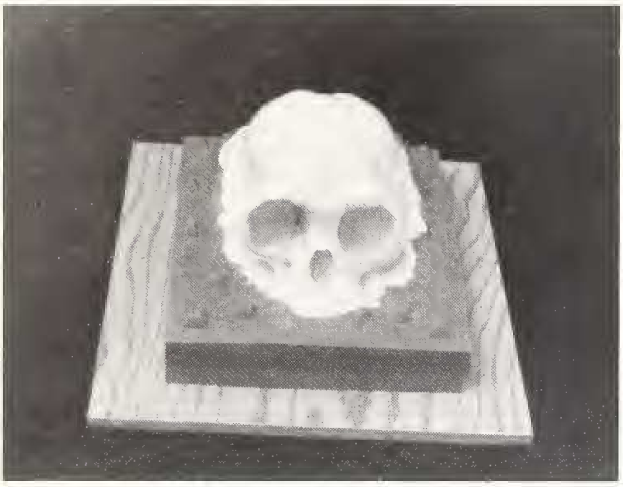

Figure 6. *Step 2 — First thin coat of silastic molding rubber spread over the original specimen. Care must be taken to ensure that air bubbles are not trapped between this primary coat and the surface of the original specimen.*

consequent deformation between the two halves of the mold when it is closed. During the formation of the part-line any unneeded clay should be removed to ensure a precise, continuous junction between the clay and the specimen.

A series of elevated tabs, and/or regular depressions, are placed at regular intervals around the specimen to act as registration guides. These tabs should be angular with flat, beveled edges. Lastly, the edges of the clay slab should be cut to make a square or rectangle with sharp vertical sides. This will also assist in proper registration of the two halves of the closed mold.

Step 2

This is the most important step during the molding procedure. Great care must be taken to ensure that no air bubbles are trapped at the boundary of the object's surface and the first coat of molding rubber. The subsequent layers of the rubber serve only to strengthen the primary coat so that the finished mold can only provide as much detail as the first layer of molding rubber. The entire surface of the original specimen must be coated in a thin layer of molding rubber with no air bubbles at the rubber-specimen interface.

The silastic rubber and curing agent should be thoroughly mixed immediately before using in the ratio recommended by the manufacturer. After mixing, the rubber should be deaerated to reduce air bubbles that were introduced during mixing. The mixed molding rubber is placed under vacuum (approximately 25mm pressure) until it completely expands and recedes to its original level. Experience will dictate the amount which can be vacuumed at one time. Caution should be exercised to guard against the expanding rubber overflowing its receptacle and being drawn into the hose connecting the vacuum pump and bell jar. We find that large disposable plastic or paper cups are satisfactory for vacuuming the rubber. Avoid Styrofoam cups for this purpose. After the molding rubber has been vacuumed a disposable wooden spatula works well as a tool for spreading the liquid silastic over the original. However, touching the surface of the specimen should be avoided and a stream of compressed air should be used to direct the liquid molding rubber over the surface and especially into small cracks, crevices or undercuts. In the case of small specimens or difficult to reach areas a small, clean paint brush combined with compressed air can be used.

Often under field conditions neither a vacuum pump nor an air compressor is available. In this situation, less vigorous stirring and mixing of the molding rubber is advisable to reduce the introduction of air into the mixture. The air which is inevitably introduced into the molding

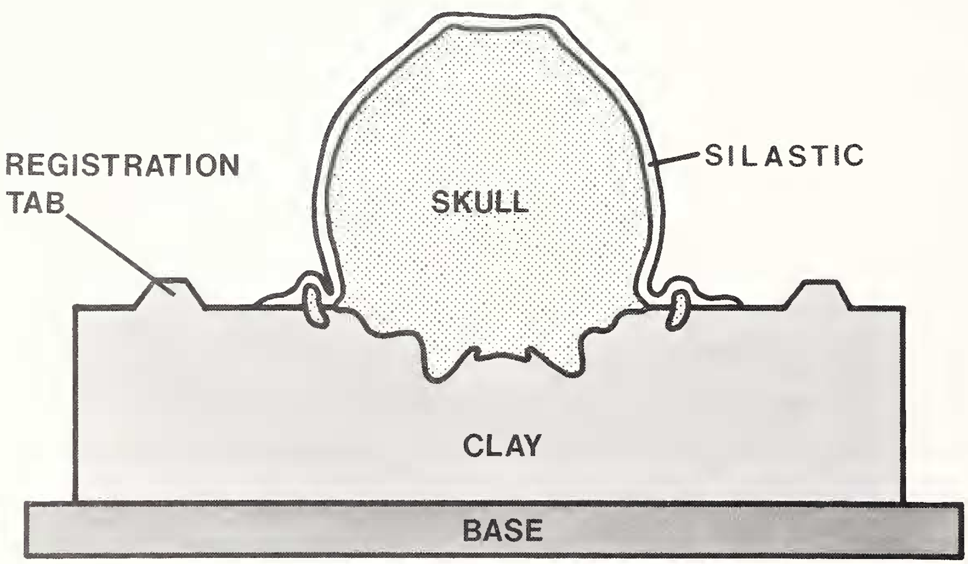

Figure 7. *Step 2 — Coronal section.*

FIGURE 8. *Step 3 — Second coat of silastic molding rubber applied and clay retaining walls added. Areas on photograph have been shaded to highlight detail.*

rubber during the mixing process will coalesce into bubbles which gradually rise to the surface of the liquid rubber. It is therefore necessary to check the liquid rubber which has been placed over the specimen approximately every 20 minutes (for the first hour) in order to remove these bubbles. The number of bubbles can also be reduced by mixing the silastic in a paper cup and allowing the mixture to stand for about ten minutes; a period which allows the air bubbles to rise to the top. A small hole can then be cut in the bottom of the cup and the silastic poured over the specimen through this hole.

An additional aid is to use a stream of compressed air which can be created by attaching a hose to the valve of a spare tire which has been previously overinflated. Any bubbles rising to the surface of the silastic can be removed by directing the air across them. Although this may appear to be additional work, special care must be taken to avoid entrapment of bubbles at the part-line or the rubber-specimen interface.

Step 3

A second thin coat of silastic is applied after the initial coat has vulcanized (approximately 24 hours) and retaining walls of clay are built around the mold. We do not recommend placing retaining walls around the mold any earlier than this stage. The reason is to permit easy access to all areas of the specimen during the first, crucial coat. Again, the mold and the retaining walls should be angular to assist registration.

Step 4

Additional coats of RTV E are applied until approximately 3mm of the material evenly covers the specimen and surrounding clay base. It is important to wait the recommended amount of time between coats as improper curing might otherwise ensue. Importantly, thicker and more layers of silastic are not necessarily better because the thicker the silastic, the less flexible the mold and the more difficult the unmolding process. To avoid creating a rigid, solid block of silastic completely covering the specimen, ground cotton or cabosil can be added to decrease the fluidity of the silastic so that it can be applied to strongly contoured surfaces and/or deep indentations. In addition, surgical gauze can be placed over the external surface of the mold to serve as a strengthening agent.

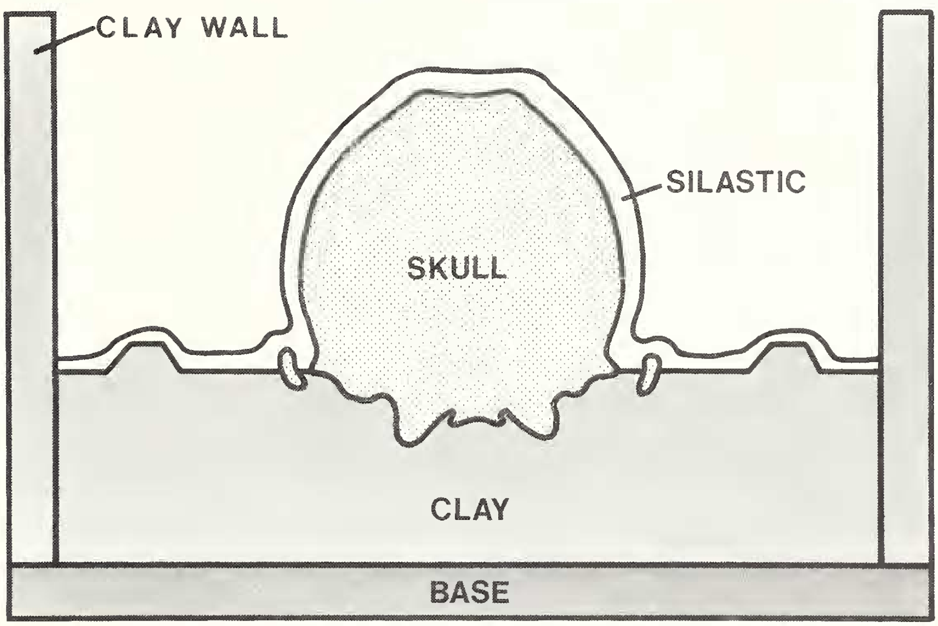

FIGURE 9. *Step 3 — Coronal section.*

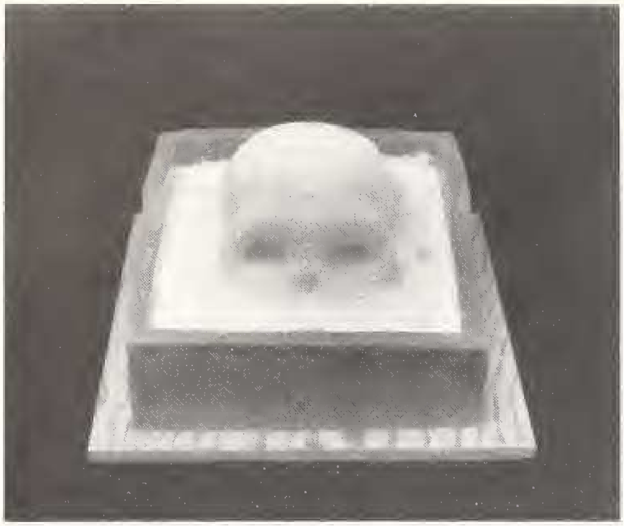

FIGURE 10. *Step 4 — Final coat of silastic molding rubber applied to this half of the mold. Note that gauze has been applied to the specimen at this stage to increase strength of the rubber. Note also that the gauze and rubber follow the natural contours of the original specimen.*

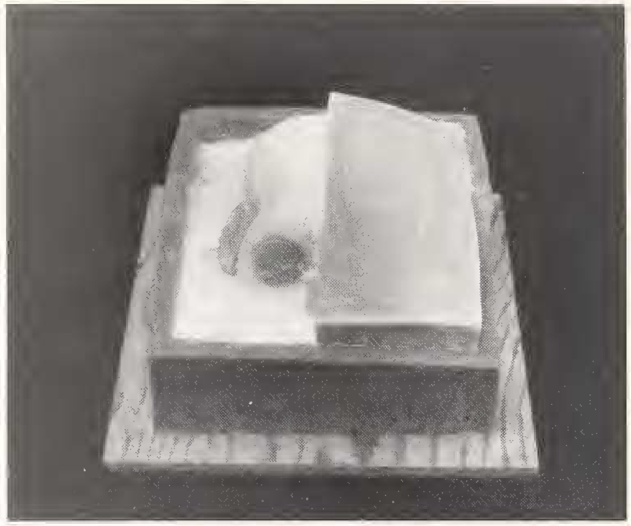

FIGURE 12. *Step 5 — Completed half of mold. Plaster jacket partially cut away to demonstrate the shape and position of plaster inserts. Note also the addition of silicone rubber registration tabs.*

A set of small, precut registration tabs of hardened rubber are affixed to the surface of the final coat of uncured silastic to firmly secure the mold to the plaster jacket. These registration tabs should have flat, beveled edges to ensure easy removal of the plaster jacket which is described in the following step.

Step 5

A plaster jacket ("mother mold") minimizes distortion in the flexible silastic rubber mold. In the absence of a plaster jacket, any pressure on the highly flexible rubber mold can potentially result in a distortion of the original contours and subsequent error in the cast. The external surface of the rubber mold must be smooth to prevent adherence of the plaster jacket and any roughened area should be covered with a coat of vaseline. In addition, a liberal coating of talcum powder over the silastic will also help the removal of the plaster jacket.

Before pouring the plaster for the external jacket, all undercuts and insets (*e.g.* orbits) are filled with individual

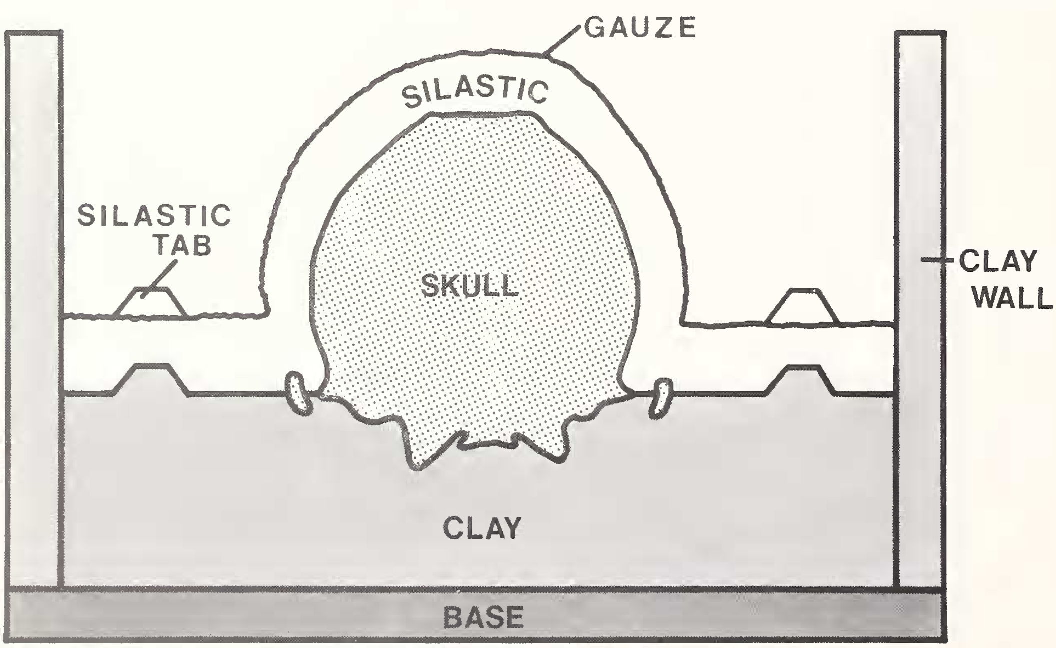

FIGURE 11. *Step 4 — Coronal section.*

plaster plugs (Figures 12 and 13). These plugs are liberally covered with vaseline to prevent their bonding to the jacket.

Gypsum Hydrocal A-11 plaster (Appendix 1) is a good, jacketing material. A single layer of fast setting plaster bandage (Appendix 1) applied initially, will strengthen the jacket. The addition of sissal fiber to the liquid plaster can also be used to strengthen and contour the plaster jacket. Fiberglass also makes a rigid yet lightweight material for jacketing.

Step 6

The clay walls and base are removed and the half finished mold is inverted. Any clay adhering to the specimen and the surrounding silastic is carefully removed. Check especially for traces near the surface of the part line by gently pulling the silastic away from the specimen in the area of the part line. Having done this, it is necessary to make sure that the silastic edge returns exactly to the established part line and does not pucker against the edge of the specimen.

A thin coat of release agent (petroleum jelly dissolved in trichloroethane, CH_3CCL_3) is then painted over the exposed silastic, care being taken not to wet the original specimen. The petroleum jelly trichloroethane mixture will create the part line by ensuring that the silastic layers will not bond to each other. Care should be taken to coat the entire exposed surface of the silastic or else adherence will occur between the two sides.

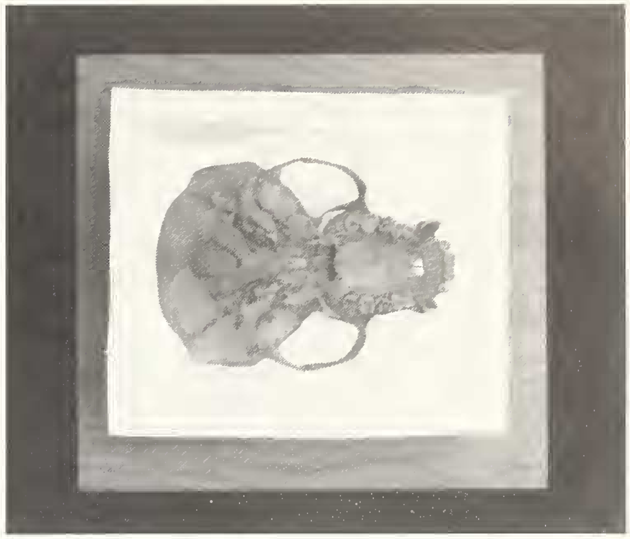

Figure 14. *Step 6 — The mold has been inverted and clay removed. The release agent has been applied to the silastic rubber surface and the specimen is now ready for the next step.*

Step 7

Steps 2-5 are repeated for the exposed half of the skull. During the casting procedure a mold is normally taped closed, but we have found that it is advisable to incorporate a threaded bolt system into the design of the larger, heavier molds. During the first step of the molding

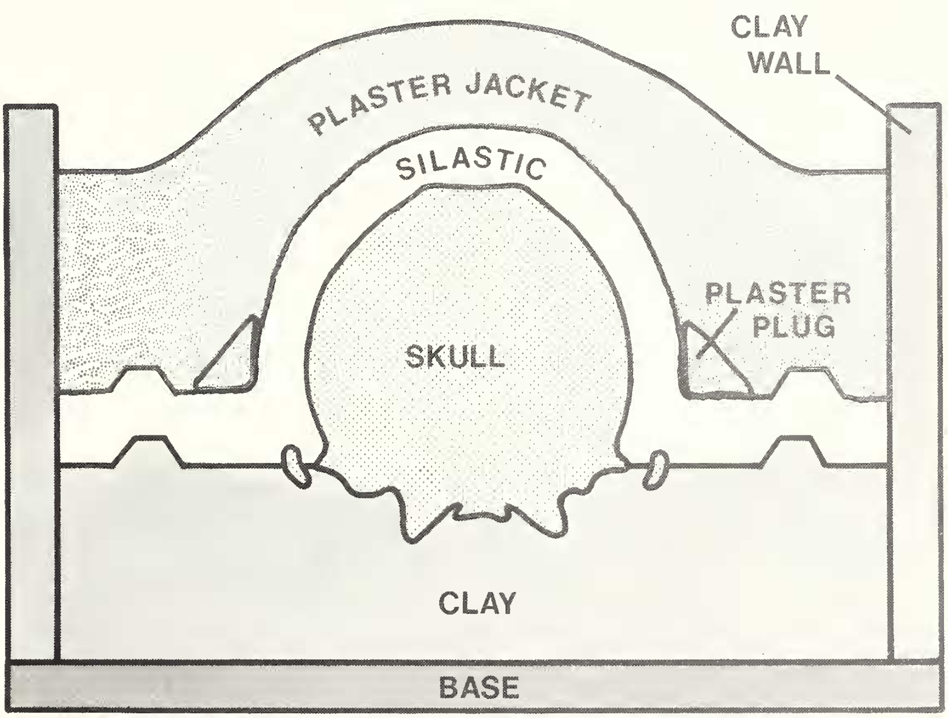

Figure 13. *Step 5 — Coronal section. Plaster jacket shown in its entirety.*

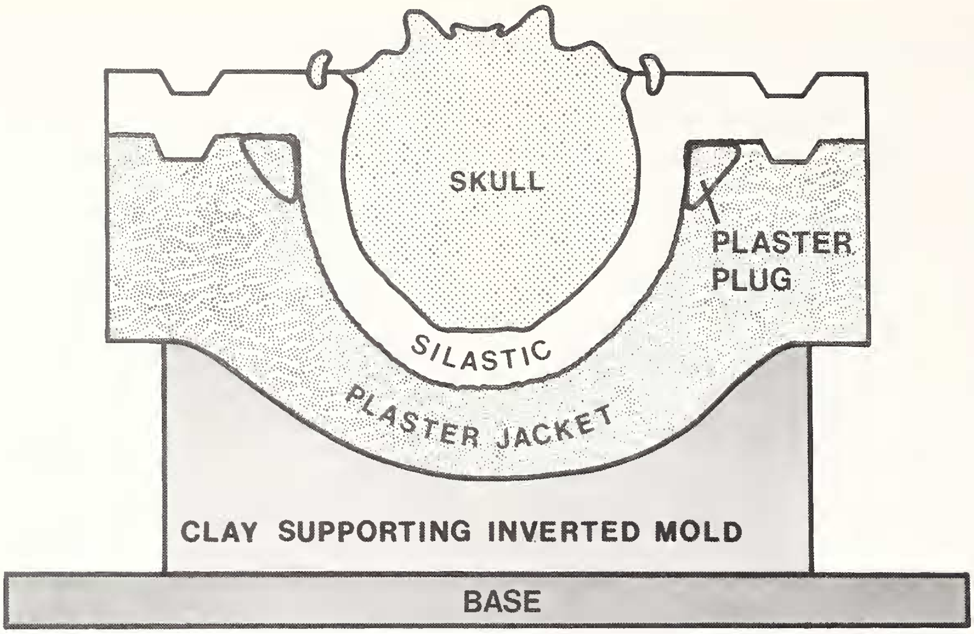

FIGURE 15. *Step 6 — Coronal section.*

procedure, four unthreaded metal rods (equal in diameter to the bolt) should be placed vertically in the clay base, one in each corner. The rods should stay in position throughout Steps 1 - 7 to ensure that the holes for the bolts through the rubber and jacket are properly aligned. The plaster jacket can be reinforced with a piece of hollow, threaded steel lamp pipe placed over the rods during Step 5. Four threaded bolts closed with wing nuts will give excellent registration for larger molds.

To unmold the original specimen, the external jacket is first removed. The two rubber halves are then carefully separated as far as the specimen, care being taken not to twist or damage the original. The two halves of the mold are then cautiously peeled away from the specimen taking special care in the areas of foramina and undercuts. Upon removal of the original specimen, the molding process is nearly complete. The final step is cleaning and restoring the original specimen.

Wear and tear of the mold surface occurs from the moment the original specimen is removed. Occasionally, small pieces of the molding rubber caught in cracks and crevices may tear away during the unmolding process, emphasizing the importance of good preparation before molding. Torn pieces of the mold can be reattached by gluing with Silicon RTV 700 (Appendix 1). These repairs are temporary and have to be repeated each time a cast is poured.

The first cast is the most accurate and can be saved as a "record". Then, if and when a second mold is required, the record cast can be used in place of the original. In fragile and rare fossil specimens it is especially critical to use a "record cast" for remolding in order to keep the original as pristine as possible. We use hardened dental stone (see below) for our record casts because of its dimensional stability. This material, although very hard, is brittle and easily broken. Record casts, therefore, should always be placed in a protected area and not handled. Also, because of the natural fragility of the dental stone casts we usually pour two record casts. A final note concerning record casts is our recommendation not to clean the flash lines off the cast. By leaving the flash, if and when it becomes necessary to remold the specimen, the technician can easily recognize and duplicate the original part-line.

Casting

Accurate casts can be poured in a variety of materials, including plastics, epoxy compounds and plasters. These materials vary in terms of physical properties, working times and cast detail. Therefore, the casting materials should be chosen on the basis of the number of casts needed and the ultimate use of casts. Because these various materials differentially effect mold life, thought should also be given as to the total number of "pulls" needed. We recommend the use of the following materials because they produce dimensionally stable, highly detailed casts while minimizing mold damage.

Casting in Plaster

Coecal (Appendix 1) is a dimensionally stable, chip resistant dental stone that gives excellent detail. We have found that mold life using Coecal is excellent; 25-35 "pulls" as opposed to 15-20 "pulls" for plastic casts. The trade off is, of course, the natural fragility of the dental stone relative to the more durable plastics. Prior to the introduction of the liquid dental stone into the mold, a mold dressing (Appendix 1) is painted on the mold's internal surface to reduce surface tension and prevent the

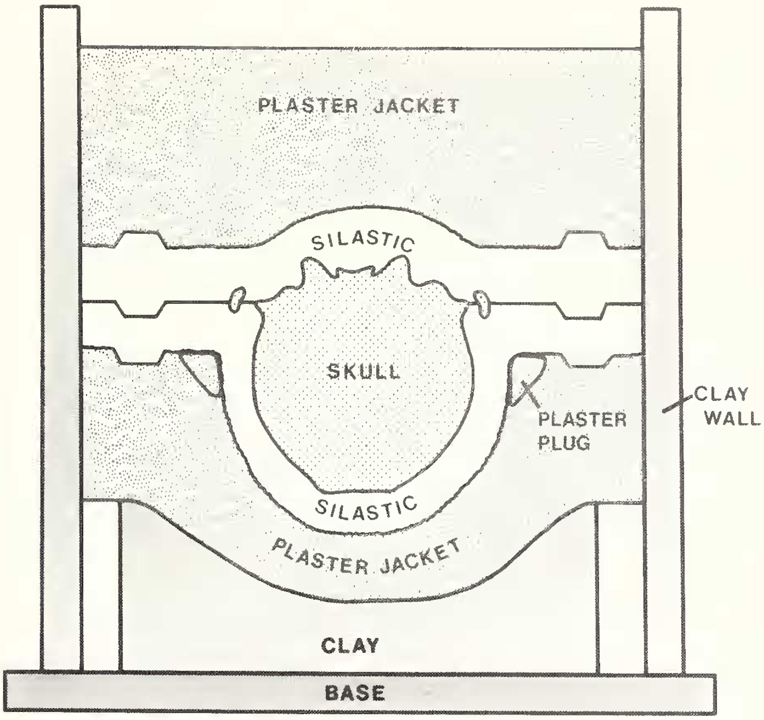

FIGURE 16. *Coronal section of completed mold. See text for details.*

entrapment of air bubbles. Coecal dental stone is mixed with liquid Gypsum Hardener (Appendix 1) at a ratio of 100:34 by weight, in a Whip-Mix machine under vacuum. Gypsum Hardener is used in place of water because it reduces the pore spaces and increases the compressive strength of the dental stone. However, one cautionary note must be added regarding the use of Gypsum Hardener instead of water. The liquid hardener significantly hastens the "setting time" and as a consequence reduces the handling time.

Prior to actually filling the mold halves, small indentations and concavities should first be injected using a disposable dental irrigation syringe (Appendix 1). The two parts of the mold are then filled with liquid plaster over a vibrating plate to dislodge trapped air bubbles adhering to the surface of the mold. Just before closing, a little extra plaster should be added to both halves of the mold, which are then held side-by-side one in each palm and "slapped" shut. When first practicing this procedure it is advisable to wear a lab coat.

The mold should immediately be taped (using fiber strapping tape; Appendix 1) or bolted closed to prevent the loss of the liquid plaster. Importantly, if using a threaded bolt system, the wing nuts should never be secured beyond "finger tightness". Any further pressure will distort the mold and lead to shearing along the plane of the part-line. In addition, in especially large molds the small amount of expansion that occurs when the plaster hardens can actually crack the mold jacket if it is tightened too securely.

To prevent a bubble from coalescing on the surface of the cast, the mold can be rotated by hand for two to three minutes while the plaster hardens. If deemed necessary, extra plaster can be added after the mold is taped shut by gently inserting the nozzle of a syringe between the mold halves and injecting liquid plaster. This latter step is often required if large amounts of liquid plaster are spilled during the closing of the mold halves.

Dental stone casts can be solid or hollow. For hollow casts the ratio of dental stone to Gypsum Hardener is increased to 100:36 by weight to increase the handling time and the mold is rotated in the casting machine (Appendix 2).

Casting in Plastic

Frequent use of epoxies should be avoided as epoxies chemically contaminate silicone rubber reducing mold life. Manufacturer specifications recommend the use of polyesters and polyurethanes as casting materials with RTV E. We have found that a 50:50 mixture (by weight) of two polyurethanes (Dynacast and Master Cast 750; Appendix 1) gives excellent detail and minimizes mold damage (after 15 "hollow" castings most molds show no appreciable damage). However, Master Cast and other polyurethanes are extremely sensitive to moisture and should be mixed in plastic containers with metal or plastic utensils. A thin coat of silicone sprayed over the mold surface will facilitate unmolding and can also help protect the mold rubber from contamination.

Dynacast and Master Cast are 2-component thermosetting urethane plastics. Precautions therefore must be taken to prevent the formation of the small air bubbles in the finished cast, which are the by-product of the heat produced by the chemical reaction in the plastics. "Shelling" the mold surface with a thin coat of liquid plastic using a disposable brush will reduce volume and heat and ensures an even flow of plastic over the entire mold surface. In difficult to reach areas, (*e.g.* teeth, styloid processes, pterygoid plates) plastic should be injected using a plastic disposable dental irrigation syringe. After approximately an hour, when the first coat of plastic has hardened, the mold should be filled 2/3 full of the liquid plastic, closed, and taped or bolted shut. Again, as with the plaster, extra plastic can be injected into the closed mold using a disposable syringe. The silastic is flexible enough to insert syringe tip gently between the two halves of the mold.

Because this mixture of urethanes thickens fairly rapidly (has a working life of less than ten minutes) handling time is an important factor. The filled mold should be wrapped to prevent spillage and fastened onto the rotating machine (Appendix 2) while the plastic casting material is still liquid. Although no longer liquid after 20 minutes the plastic remains malleable and the mold should be rotated for approximately an hour.

Hollow casts can be poured in Dynacast alone. Dynacast, however, has a pot life of only five minutes (at 25∞C) and it takes an experienced caster to work under these conditions. Most casts can be unmolded four hours after closing the mold. However, the urethanes often remain somewhat malleable in small casts and should harden for at least six hours before unmolding. We generally leave urethane casts in a well ventilated area (under a fume hood) for 24 hours after unmolding for the completion of the curing process.

Finishing Techniques

When the casts are fully hardened, the flash along the "part" line is trimmed with a scalpel. A well-registered mold produces casts that have an all but invisible part line. This is especially important when painting, as the part-line takes pigment differently from the surrounding casting material. Small defects or bubbles are filled with plaster, urethane or epoxy putty. Positive bubbles caused by defects in the mold surface can be flicked off with a needle point. Painting can duplicate either the original color(s) or, in a study cast, enhance surface detail. Record casts should always remain unpainted as pigment will obscure surface detail during the remolding process.

Painting Plaster Casts

Dry artist's pigment dusted over the cast's external surface and sealed with an acrylic agent (Appendix 1) highlights detail by filling cracks and fissures. For study casts, a wash of Grumbacher raw umber pigment mixed in acetone will intensify surface detail. Lightly rinsing with water will ensure an even distribution of color over the surface of the cast. A mixture of dry pigments, acrylic paints and magic markers can also be used to duplicate the original colors.

Painting Plastic Casts

Plastic casts are more difficult to color, owing to the material's natural impermeability and repellency to liquids. However, liquid and/or dry pigments can be applied to the mold's internal surface prior to adding the plastic. Upon hardening, the plastic will bond to the pigments, resulting in a permanent finish. This method, although time consuming, gives excellent results. Plastic casts can also be colored by painting the external surface after unmolding. A satisfactory paint is obtained by dissolving acrylic pigments in a liquid matte medium to which an Acrylic Flow Improver (Appendix 1) has been added (2 parts to 20). An acrylic flow improver slows the setting time which is important if an even color is required. Reconstructed areas can be delineated with acrylic or enamel paints. Special urethane pigments are available and can be added while mixing. Difficulties arise, however, in obtaining identical shading if casts or portions of the cast are poured at different times.

Conclusion

These molding and casting techniques are the result of experimentation over the past 12 years in the Laboratory of Physical Anthropology. The methods described are easily learned and enable the production of economical, dimensionally stable, high resolution casts, that are suitable for display, research and educational purposes. △

Appendix 1

Materials

The materials listed below are those currently being used in the casting laboratory at the Cleveland Museum of Natural History. This list includes materials that we have chosen through extensive trial and error.

Molding Materials and Equipment

- Silastic RTV E molding rubber: Dow Corning, Midland, Michigan.
- Silicon RTV 700: General Electric Silicone Products, Waterford, New York.
- Glyptal Lacquer Cement 1726: General Electric, Schenectady, New York.
- Plastalina Leisure Clay #10422: Leisure Craft Company, Compton, California.
- CH_3CCl_3 Trichloroethane: Fisher Seientific Company, Springfield, New Jersey.
- Kling rolled surgical gauze: Johnson and Johnson, medical supply store.
- Fast setting plaster bandage: Johnson and Johnson, medical supply store.

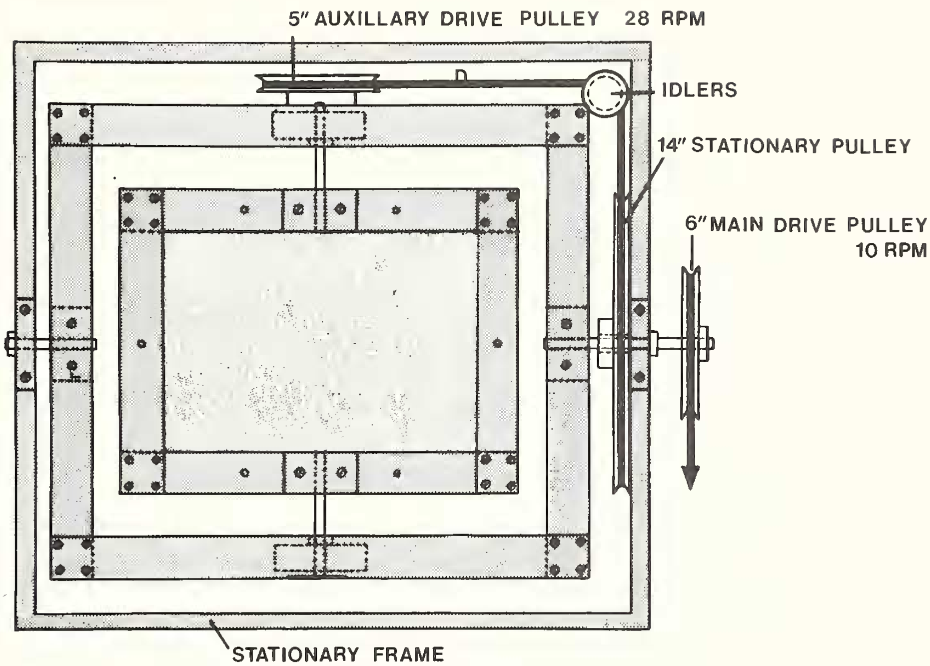

FIGURE 17. *Schematic diagram of the rotating casting machine used in the casting laboratory at The Cleveland Museum of Natural History. See Appendix 2 for details.*

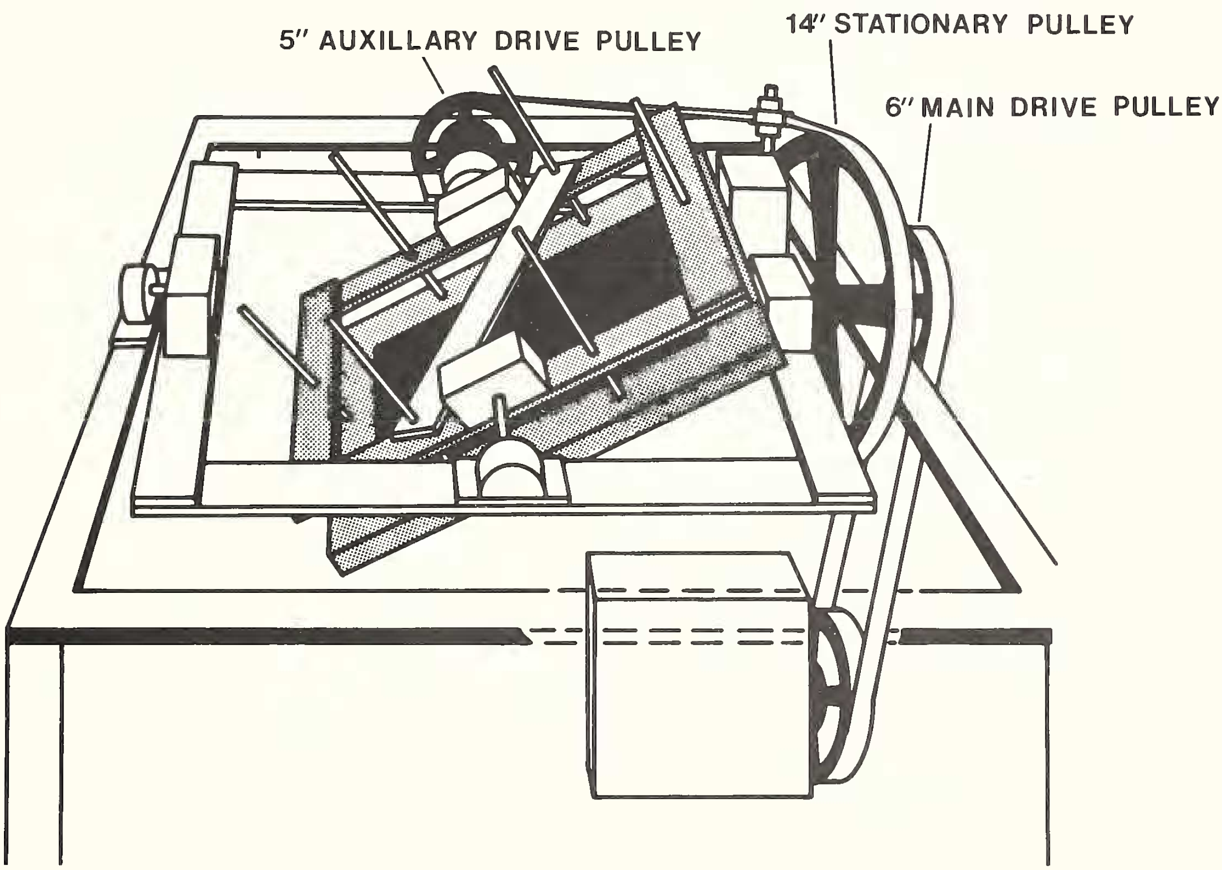

FIGURE 18. *Diagram of the rotating casting machine, shown in previous figure. See Appendix 2 for details.*

- Hydrocal Plaster A-11: United States Gypsum Company, Chicago, Illinois.

Casting Materials and Equipment

- Dental Stone (Coecal plaster): Coe Laboratories Inc., Chicago, Illinois.
- Plaster Gypsum Hardener: Whip Mix Corporation, Louisville, Kentucky.
- Permaflex Concentrate Mold Dressing: Permaflex Mold Company, Columbus, Ohio.
- Whip Mix Casting Vacuum Mixer, Model B: Whip Mix Corporation, Louisville, Kentucky.
- Dental Irrigation Syringe, Type #8881-411012 Curved Tip: Monoject; Sherwood Medical, St. Louis, Missouri.
- Dynacast: Kindt Collins Co., Cleveland, Ohio.
- Master Cast 750: Kindt Collins Co., Cleveland, Ohio.
- Pure Silicon Spray, Cat. #3302.7: Brookstone Company, Peterborough, New Hampshire.
- Tape, Scotch Brand Tape No. 898.
- Dry Pigment: Grumbacher Artist Quality Dry Color, art supply store.
- Acrylic Agent #1303 Crystal Clear Acrylic Spray Coating: Krylon, art supply store.
- Liquid Acrylic Matte Medium: Liquitex, art supply store.
- Acrylic Flow Improver: Windsor and Newton, art supply store.

Appendix 2

Casting Machine

The rotating casting machine permits the production of "hollow" plastic and plaster casts by rotating the molds as the liquid casting material hardens. The machine rotates the mold slowly in three dimensions, allowing the casting material to flow equally on all internal mold surfaces. It is important that the machine not develop sufficient centrifugal force to overcome gravity and that the auxiliary and main shafts not turn at identical RPM values. In our machine we use different sized pulleys producing a speed of 10 RPM for the main shaft and 28 RPM for the auxiliary shaft. The platform upon which the mold is secured is recessed and adjustable so that the center of mass can be concentrated near the rotational axes.

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